ILLUSIONS IN THE PERCEPTION OF SHORT TIME INTERVALS

BY
NATHAN ISRAELI, A. M.

L. C.

Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in the Faculty of Philosophy, Columbia University

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Illusions in the Perception of Short Time Intervals

Introduction

The perception of short time intervals is subject to different conditions. It is tied up with rhythm effects, as shown by Meumann,[1] and with pattern effects, as in the experiments of Woodrow.[2] Whether or not an investigation of the perception of short time intervals is of great practical interest, it has much promise for theoretical psychology as it leads to a knowledge of the fundamental activity involved in the perception of time.

The present investigation makes a fairly systematic experimental exploration of a simple situation consisting of three or four successive flashes of a light. This series of flashes constitutes a pattern which includes a main interval between two flashes, and a preceding or succeeding interval. The situation is simplified because the stimuli are of one sense modality, *lights* only.

Four experiments were made which, with the third experiment disregarded, constitute a continuous series. This study can be described as a systematic exploration of illusions in the perception of a short time interval when an extra stimulus comes before the main interval (Exp. I), within it (Exp. IV), or after it (Exp. II). An analysis is made of the corresponding errors in the observers' estimation of the main interval duration as an extra stimulus is shifted from the main interval, through it, and after it.

---

[1] *Philos. Stud.*, 1894, 9, 264-306.

[2] A quantitative study of rhythm. *Arch. of Psychol.*, No. 14, 1909. Behavior with respect to short temporal stimulus-forms. *J. Exper. Psychol.*, 1928, *11*, 167-193, 259-280. Only the 1928 reports will be alluded to in the text.

CHAPTER I

The Problem and Historical Summary

1. The problem. The purpose of this investigation is to study changes in the perception or judgment of a constant time interval that lapses between two stimuli when (1) the constant time interval is preceded by a variable time interval (Exp. I); (2) the constant time interval is succeeded by a variable time interval (Exp. II); (3) the constant time interval is both preceded and succeeded by a variable time interval (Exp. III); (4) the constant time interval is divided into two variable intervals (Exp. IV).

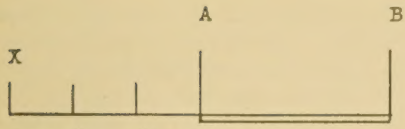
The constant interval is to be considered as the main interval. These four cases are represented diagrammatically in Fig. 1. A and B in the various diagrams represent the stimuli limiting the main interval of time that is to be reproduced by the observer. X represents the extra stimulus that precedes A; Y the extra stimulus that comes between A and B; Z the extra stimulus that comes after B. *X-A-B, A-Y-B, A-B-Z, X-A-B-Z* will designate the stimulus-patterns in the different experiments, being named after the stimuli limiting the main interval, the extra stimulus marking off an interval preceding or succeeding the main interval, and dividing the main interval.

Any deviation in the perception of the main interval from the objective duration of that interval constitutes an illusion. By objective duration of an interval is meant time measured by a clock. The problem of this research is to study comparatively the errors that occur in the perception of the main interval in each case. These errors are indices of the magnitude of the illusions. The interest lies in the changes in the magnitude of the illusions.

2. Historical summary. This research originated in the 1928 report of Woodrow, on certain illusions in the estimation of short time intervals.[3]

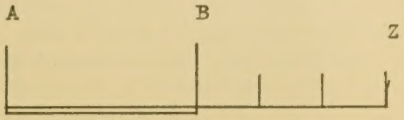
In the work of Woodrow, stimulus-forms consist of an interval and its boundaries. An interval of time is a period of silence between two sounds of variable length. A stimulus-form is designated by letters representing the duration of the

[3] *Op. cit.*



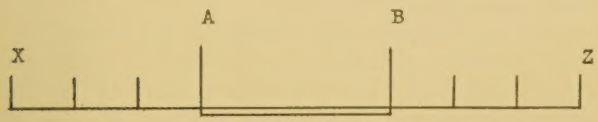
An extra stimulus X comes one, two or three units before the interval A-B.

DIAGRAM A - EXP. I



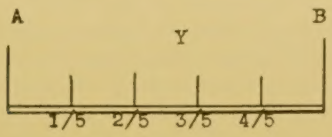
An extra stimulus Z comes one, two or three units after the interval A-B

DIAGRAM B - EXP. II



An extra stimulus X and an extra stimulus Z come one, two or three units before and after the interval A-B.

DIAGRAM C - EXP. III



An extra stimulus Y comes within the interval A-B along the fifths.

DIAGRAM D - EXP. IV

FIGURE I. DIAGRAMS OF THE EXPERIMENTS.
The main interval is represented by the double horizontal lines.

boundaries. In the nomenclature adopted, a dash (—) represents the interval, and the letters *s*, *m* or *l* designate the relatively short (.08 sec.), medium (.29 sec.), or long (.50 sec.) boundaries. *S-l*, for instance, represents a stimulus-form with a short initial boundary and a long terminal one.

In general, the longer the boundary, the greater the amount of over-estimation of the interval. An interval of time bounded by a long initial sound and a short terminal one, was more *m-m* vs. *s.l*, over-reproduced or over-estimated than the same interval bounded by a short initial and a long terminal sound. This is the fundamental *s-l* vs. *l-s* illusion.

Woodrow used the method of constant stimuli principally. Twenty-nine thousand judgments were recorded from 95 subjects. The stimulus-forms compared were *l-s* vs. *s-l*, *m-m* vs. *s-l*, *m-m* vs. *l-s*, and *s-s* vs. *s-l*. It was found that *l-s* increases the apparent length of an interval more than *m-m; m-m*, more than *s-l;* and *l-s* more than *s-l*. The illusions became more pronounced with increasing number of trials, and this is said to be due not to practice effects but to the decrease in interest and attention on part of the subjects with prolongation of the experiment.[4]

The *l-s* > *s-l* illusion was confirmed by Woodrow in a brief experiment conducted by the method of minimal changes.

Over-estimation of *l-s* in comparison to *s-l* by the method of constant stimuli was paralleled in the method of reproduction experiment by a greater over-reproduction of *l-s* than of *s-l*. In the stimulus-forms *s-l*, *l-s*, *l-s-s*, *s-l-s*, *s-s-l*, *l-s-l*, *s-s-l-s*, the illusion of *l-s* > *s-l* held not only in the simple but in the more complex forms, all the sub-intervals being reproduced in addition to the boundaries. Woodrow concluded that a "particular sub-pattern exercises an influence which remains constant irrespective of the total pattern into which it enters and of any effect exerted by the latter."[5] He found the method of reproduction with graphic record to be laborious; and the procedure was restrictive as only two stimulus-forms were compared at a time. In the comparison of *s-l* and *l-s*, there was a series of thirty stimulus-forms, the first five being *l-s;* the next ten, *s-l;* the next ten, *l-s;* the last five, *s-l*. An average excess of + .133 sec. was found for the CE of *l-s* over that of *s-l*.

[4] *Op. cit.*, p. 185.
[5] *Op. cit.*, p. 280.

Woodrow's explanation of the illusions rests upon the assumption that the whole pattern affects the reproduction of its parts and that an analytic attitude cannot be maintained because an interval cannot be "caught" apart from or to a neglect of the limiting sounds.[6]

3. The preliminary experiments. A more systematic study than that made by Woodrow would carry an extra stimulus right through from before the main interval, into it, and after it. The preliminary experiments were devised to determine whether there are any changes in the errors corresponding to the change in the time of the extra stimulus, in relation to the main interval.

Woodrow's research was the basis of my preliminary investigation. Several experiments were tried out, in which the observers reproduced a constant interval of time, preceded in one case and succeeded in another by a variable time interval. It was found that there was a change in the accuracy and in the consistency in the reproduction of the constant time interval, as the interval before it or after it was made longer. Another experiment was devised from these experiments in which a constant interval of time, divided by an intervening extra stimulus, was reproduced by the observer. With the change in the position of the intervening extra stimulus, there was a change in the magnitude of the resulting illusions.

In the experiments just discussed, all the stimuli were of the same duration, and only lights were used, whereas in all Woodrow's experiments sounds of varying length were the stimuli bounding the time interval. I repeated Woodrow's experiment with LIGHTS (instead of SOUNDS) of varying duration, bounding the constant interval. Woodrow's illusions were confirmed in that the *l-s* illusion exceeded the *s-l* illusion, as measured by the method of constant stimuli.

The final technique was developed in the preliminary experiments. The method of reproduction with an electric stopwatch instead of graphic records was found to be highly economical and expedient because it allowed different stimulus-forms to be put into play in chance order. It was found necessary to introduce a control: (1) to measure the daily

[6] Woodrow's subjects reproduced all the boundaries and intervals of a stimulus-pattern. Perhaps, to create an *analytic attitude*, only the time of the main interval should be reproduced.

general trend in the accuracy and consistency of the observers; (2) to measure the accuracy of reproduction of a plain interval, (that is, an interval of time lapsing between two stimuli A and B); (3) to gauge that complex of factors recognized by Woodrow as influencing the reproduction of a time interval. This complex of factors is said to be "such internal processes . . . 'set,' subjective grouping, manner of apprehension of the stimulus-form, accuracy of perception of finger-movements, initiation and execution of movements."[7] He did not, however, attempt to measure this complex of factors, as I did in my controls.

In these preliminary experiments, over 6,500 judgments were obtained from nine subjects who served throughout a set of experiments.

[7] *Op. cit.*, p. 275.

PLATE I-A. PANEL SWITCHBOARD, AUXILIARY SWITCHES, SIGNAL APPARATUS, TIME-SENSE MACHINE AND MOTOR.

Left to Right—Central Control. Three major switches to operate interval contact lights; Control Panel Switchboard with six double-throw single-knife switches controlling the twelve time-machine contacts; Stop-watch; General cut-out key; Stop-watch key; Time-machine warning signal to experimenter; Switch to buzzer; Switch to lights or stop-watch; Time-sense machine and reduced Gear Drive.

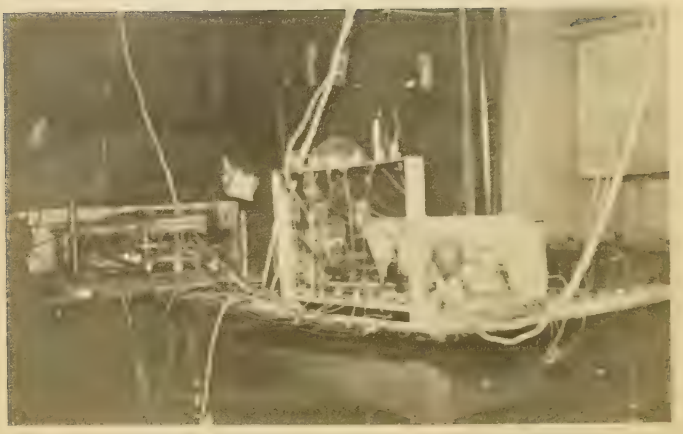


PLATE I-B. REAR VIEW OF PANEL SWITCHBOARD SHOWING THE BEAVER RELAY AND THE TIME-SENSE MACHINE.

CHAPTER II

Apparatus and Method

1. Apparatus. A time-sense machine was used in this investigation to control the timing of a visual stimulus. The machine regulates the time between several light flashes and enables the experimenter to present stimulus-patterns consisting of a main time interval preceded or succeeded by a variable time interval.

On the circumference of the time-sense machine, 12 mercury contacts are so set as to regulate the time between the light flashes. The contacts are connected to a switchboard (Plate 1). The time-sense machine is driven by a pulley, connected to an A. C. motor with a reducing-gear system. A bar rotates around the circumference of the time machine. As it sweeps over a mercury contact,[8] connected by a switch with the main circuit, the circuit is completed, and the neon tube is flashed. The time-sense machine activates a Beaver relay circuit,[9] and, according to switch connections, may either light a neon tube or operate a stop-watch. Sparking is eliminated at the mercury contacts by this relay circuit.

A neon tube was used to give a sharp, clear (orange) flash, with no lag. This tube was mounted inside a specially designed light-tight box (cemented with plastic wood). The tube plate was perpendicular to the line of vision. The center of the tube plate was 3¼ in. from a slit between two metal strips. The slit was 4/1000 in. wide, and ¾ in. high. It was 23⅛ in. from the head-rest, which was borrowed from an ophthalmometer.

Through a common minor relay circuit, the time machine, observer or experimenter could operate the stop-watch. The hook-up represented in Plate II shows the Beaver relay, the time-sense machine and switchboard, the neon, and the minor relay stop-watch circuits.

The time marked off by the mercury contacts is measured by

[8] The maximum surface width of the triangular mercury contacts measures 3.5 degrees. A contact wire suspended from the rotating arm is set to sweep over the central part, which is approximately half the maximum surface width of the contacts. The time of the flash is .021 sec., when the degrees are converted into units of time (from the data in Tables I and II).

[9] D. J. and J. J. Beaver, *Jr. Ind. & Eng. Chem.*, 1923, *15*, 359.

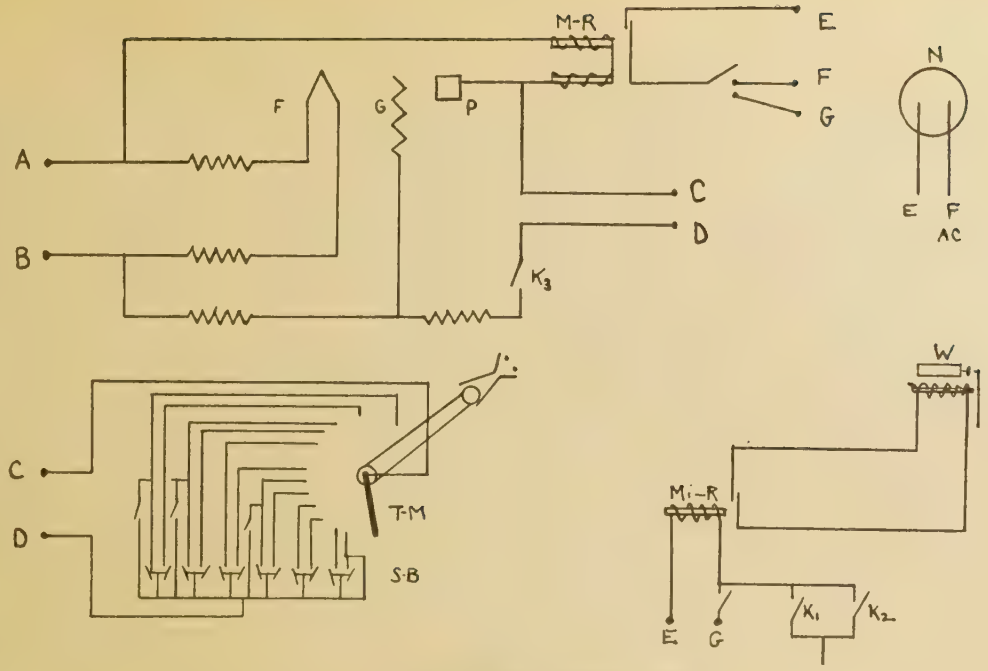


PLATE II. HOOK UP OF THE DIFFERENT CIRCUITS.

Explanation

1. *Upper Left*—Beaver relay circuit. A and B, direct current lines; F (filament), G (grid), P (plate) are parts of the vacuum tube; M-R, major relay operating either a neon tube through EF or a stop-watch through EG. K_3, central switch.

2. *Lower Left*—Time-machine circuit. T-M, time-machine driven by a belt connected with an alternating current motor—with a bar rotating around its circumference sweeping over twelve different mercury contacts (represented by dots). S-B is the switchboard circuit having six single-knife double-throw switches and three auxiliary switches controlling the mercury contact circuits (arranged for Exp. IV). CD, to the Beaver relay circuit.

3. *Upper Right*—EF, neon circuit (alternating current).

4. *Lower Right*—Minor relay circuit. EG, Beaver relay circuit, or K_1 or K_2, observer's or experimenter's key, may operate Mi-R, a relay, and W, the stop-watch.

The four circuits are hooked up as a unit. The time-machine circuit (lower left) activates the Beaver relay (through CD) which, through M-R, a 3,000 ohm relay, may either light a neon tube through EF or operate a stop-watch through EG. The observer also operates this stop-watch through a common relay, Mi-R.

switching the major-relay circuit on the stop-watch relay circuit. The time of the main intervals is given in Table I (Exps. I, II and III), and in Table II (Exp. IV). In Table III, a comparison is made between the sum of the time of the units into which a main interval is split with the total time of the main interval.

2. Procedure. The subjects were unaware of the purpose of the experiments. Before the sitting began, the subjects read the following general instructions:

"In these experiments, react to the intervals indicated without the use of any secondary aids. React as far as possible in a natural manner. Whistling, humming, whispering, finger-drumming, foot-beating and other such *secondary aids* should be avoided and eliminated. Try your best at all times. For the minor rest intervals the signal 'rest' will be given by three successive buzzes of a sounder. A long sound will mean 'get set,' and you are to put your head in the head-rest and keep your eyes open during the experiment."

The subject was placed in a dark, noiseless room. He saw flashes of a light in front of him, and reproduced an interval of time between certain flashes within a stimulus-pattern,

TABLE I—TIME OF MAIN INTERVALS
Experiments I, II, and III

Interval		*Series A*		*Series B*		*Series C*		*Series D*		*Av*
Machine Setting		AV	SD	AV	SD	AV	SD	AV	SD	
6-7	I	.358	.008	.360	.020	.352	.007	.354	.009	.356
5-8	II	.728	.008	.738	.013	.720	.011	.721	.012	.7268
4-9	III	1.098	.015	1.104	.015	1.088	.010	1.087	.015	1.0941
Complete Revolution		4.381	.023	4.390	.034	4.343	.073	4.350	.051	4.366

Each series is calculated in sec. to the fourth place for 25 time records taken each revolution of the time-sense machine. This table includes the time of the main intervals of the first three experiments and the time of a complete revolution around the circumference of the machine. (Machine-time Chart I.)

TABLE II—TIME OF MAIN INTERVALS
Experiment IV

Interval		*Series A*		*Series B*		*Series C*		*Series D*		*Av*
Machine Setting*		AV	SD	AV	SD	AV	SD	AV	SD	
1-6	I	.610	.012	.608	.007	.608	.013	.610	.009	.609
1-10	II	1.214	.016	1.214	.017	1.216	.013	1.210	.017	1.214
1-12	III	1.798	.021	1.800	.017	1.799	.019	1.799	.026	1.799
Complete Revolution		†4.307	.039	4.319	.050	4.320	.026	4.315	.040	4.315

*Machine settings on the circumference of the timing apparatus are referred to and the numbers (see Machine-time Chart II, bottom diagram) represent the mercury contact units.

†The time of the complete revolution differs from that in Table I as a different stop-watch was used in this experiment.

TABLE III

UNIT MACHINE TIME

A comparison of the total time of the fifths into which each main interval of Exp. IV is split with the time of the interval itself between two mercury contacts.

*Machine Setting**	*Series M‡* AV	SD	*Machine Setting*	*Series N§* AV	SD	*Combined Series Total Time*
			Interval I			*Interval I*
1-2	.111	.005	2-6	.492	.010	.603
1-3	.237	.006	3-6	.365	.006	.602
1-4	.364	.008	4-6	.240	.006	.604
1-5	.488	.006	5-6	.117	.005	.605
					Average	.6035
					Av. I†	.609
			Interval II			*Interval II*
1-3	.237	.006	3-10	.976	.016	1.213
1-5	.486	.006	5-10	.728	.011	1.214
1-7	.725	.011	7-10	.493	.010	1.218
1-8	.965	.065	8-10	.246	.008	1.211
					Average	1.2142
					Av. II†	1.214
			Interval III			*Interval III*
1-4	.364	.088	4-12	1.429	.022	1.793
1-7	.725	.011	7-12	1.078	.012	1.804
1-9	1.083	.011	9-12	.715	.010	1.798
1-11	1.422	.015	11-12	.365	.008	1.787
					Average	1.7953
					Av. III†	1.799

*Machine settings on the circumference of the timing apparatus are referred to with the numbers (see Machine-time Chart II) representing the unit setting of the mercury contacts. "1-2" means the actual time between mercury contact 1 and mercury contact 2.

†Average of the main interval—Table II.

‡Series M is the actual time from the beginning of the interval to each fifth into which it is split.

§Series N is the actual time from the fifths to the mercury contact ending the main interval.

directly after the last flash. The subject pressed down an electric key once, and then again a second time, so as to reproduce with the two taps of the key an indicated interval between the two light flashes.

Before each section of the sitting, specific instructions were given orally. For experiment I, where the variable interval precedes the main interval, the subject was instructed to reproduce the interval between the second and third flashes directly after the third. For experiment II, the interval between the first and second flashes directly after the third. For experiment III, he was told that there will be four light flashes, and he was asked to reproduce the interval between the second and third flashes directly after the fourth. For

experiment IV, where an interval is divided in two by an extra stimulus, the subject was told that there will be three light flashes, and that he was to reproduce the interval between the first and third flashes directly after the third. For the controls, instructions were to reproduce the interval between the first and second flashes directly after the second.

3. Plan of sittings. This research comprises nine sittings, distributed over a period of two months. A sitting lasted two hours, and there were two sittings a week for each subject. Experiments I, II and III were given in rotation order in the first six sittings. Experiment IV was given in the last three sittings. In addition to these experiments, controls were devised consisting of the main intervals of these experiments, without any preceding or succeeding interval. The control intervals had no extra stimulus.

The controls in the last six sittings were divided into the following four sections: the intervals of the controls were presented a number of times in a certain random order (Control 1); this random order was reversed (Control 2); the reverse random order (Control 3); the random order (Control 4). The first two control sections followed each other before the main experiment, and the last two control sections came after the main experiment. In sitting five, for example, Control 1 and Control 2 came before Exp. I, Control 3 and Control 4 came after Exp. I.

In the following plan of sittings, the different control sections of the main experiments are listed according to the sittings. The total number of times that all stimulus-patterns were presented in each sitting-section is included. Each stimulus-pattern was repeated ten times in all the experiments in each sitting, and in the last six sittings of the controls only. Several stimulus-patterns were presented in random order in each section. It is to be noted that the term *stimulus-pattern* does not imply anything but the particular combination of the main interval and the variable interval.

Sitting 1			*Sitting 2*		
Control	10	presentations	Control	10	presentations
Exp. I	90	presentations	Exp. II	90	presentations
Exp. II	90	presentations	Exp. I	90	presentations
Control	10	presentations	Control	10	presentations

Sitting 3

Exp. III	120	presentations
Exp. III	120	presentations
Control	20	presentations

Sitting 4

Control 1	50	presentations
Control 2	50	presentations
Exp. III	120	presentations
Control 3	50	presentations
Control 4	50	presentations

Sitting 5

Control 1	50	presentations
Control 2	50	presentations
Exp. I	90	presentations
Control 3	50	presentations
Control 4	50	presentations

Sitting 6

Control 1	50	presentations
Control 2	50	presentations
Exp. II	90	presentations
Control 3	50	presentations
Control 4	50	presentations

Sitting 7

Control 1	50	presentations
Control 2	50	presentations
Exp. IV	120	presentations
Control 3	50	presentations
Control 4	50	presentations

Sitting 8

Same as Sitting 7

Sitting 9

Same as Sitting 7

There was a vacation of two weeks between the first six and the last three sittings. One hour practice was given each subject before Sitting 1.

In all the sittings, the time was recorded after each 20 trials. This helped to maintain a uniform schedule of a certain number of presentations within a sitting of two hours. There were 320 presentations of the different stimulus-patterns in sitting 4, and in each of the last three sittings. The time between two successive stimulus-patterns in a sitting was varied.

Two-minute rest periods were allowed after every 20 reactions. During each of the first three sittings, there was a rest of five minutes, before the control following the experiments. Thus, in sitting 1, there was a five-minute rest period between experiment II and the control. In the last six sittings, the five-minute rest period came before and after the experiment proper. *E.g.*, in sitting 4, a five-minute rest period came between experiment III and the control after.

There were five paid observers: three psychology graduate students, one chemistry graduate student, and a Columbia College student.

4. Treatment of the results. As each stimulus-pattern was repeated ten times within a section of a sitting, in the statistical treatment the average reproduction and standard deviation were computed for every ten reproductions. The average VE (variable errors) is obtained by averaging the VE calculated for every ten observations of each observer individually. The CE (constant errors) is the amount of over-reproduction, and is calculated by the formula CE = average of

the reproductions — magnitude of interval. The standard deviation is computed by the formula $\sigma = \sqrt{\frac{\Sigma x^2}{N} - \bar{A}v^2}$ and is regarded as the VE. To determine the reliability of differences between the various reproductions, the formula $\frac{D}{\sigma_{diff.}}$ is applied with D representing the difference between the average reproductions of the compared stimulus-patterns. This is also computed for the individual observers, and then combined for the group.

CHAPTER III

Time Illusions in Experiments I and II

1. Description of Exps. I and II. This chapter will contrast the illusions in the perception of a main time interval, preceded by a variable time interval *(Exp. I)* with those in the perception of the main interval succeeded by a variable time interval *(Exp. II)*.

A stimulus-pattern *X-A-B* in the first experiment consists of three lights: X, A and B (Diagram A, Fig. 1). In the second experiment the stimulus-pattern *A-B-Z* consists of three light flashes: A, B and Z (Diagram B, Fig. 1). The time

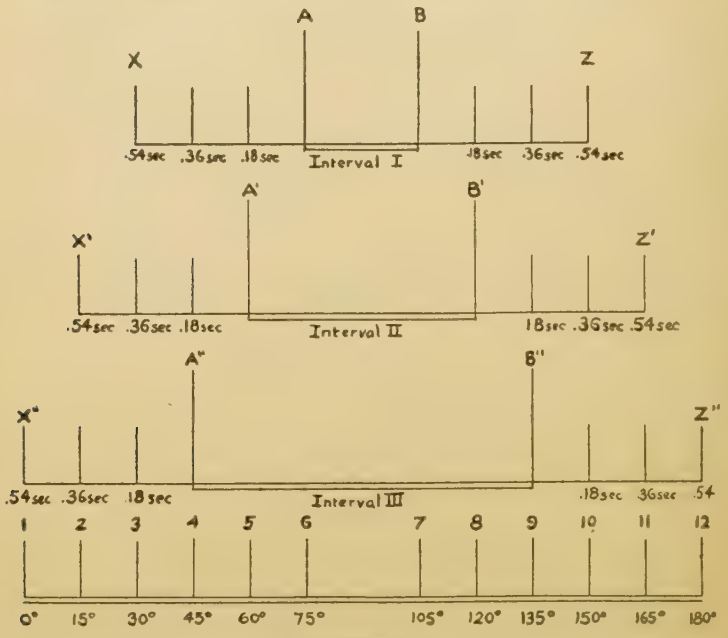


Figure 2.

Machine Time Chart I.—The upper three diagrams represent the three different main intervals with the same set of variable preceding and succeeding intervals.

The lower diagram, drawn to scale, indicates how the twelve mercury contacts were arranged on the circumference of the time machine for Exps. I, II and III. Basic unit, 15 degrees.

of the main interval A-B is constant, and this interval A-B is repeated in both experiments. In Exp. I, the interval A-B is *preceded* by a variable interval X-A, and in Exp. II the main interval A-B is *succeeded* by a variable interval B-Z.

2. Time machine settings. In Experiments I, II and III, there are the same set of three different main intervals: Interval I .356 sec., Interval II .727 sec. and Interval III 1.094 sec. All the main intervals have the same set of preceding or succeeding variable time intervals. The machine settings are shown in the *Machine Time Chart I.* A and B represent the stimuli limiting interval I; A′ and B′, the stimuli limiting Interval II; A″ and B″ the stimuli limiting Interval III. In this chart, the settings on the circumference of the time machine are drawn to scale in the bottom diagram, the unit being 15 degrees. The degrees between each mercury contact can be read from the scale. Stimuli of the three main intervals are individually represented by the longer vertical lines and of the variable intervals by the shorter vertical lines.

The contacts on the machine are so arranged that an extra stimulus may come .18 sec., .36 sec. or .54 sec. (approximately) before or after the main interval, which itself is either .356 sec., .727 sec. or 1.094 sec.

3. How the data are analyzed. The constant errors are indices of the illusions in these experiments, and a study is made of the variations in the constant errors corresponding to the changes in the duration of the variable preceding or succeeding intervals. In the following sections of this chapter, a study will be made of illusions as related to the duration of the preceding (Exp. I) and succeeding (Exp. II) intervals. The illusions in Exp. I will be compared with the illusions in Exp. II, for each duration of the variable interval.

As can be seen from the plan of the sittings, Experiments I, II and III were given in the first six sittings, and were arranged in these sittings so as to allow each experiment to be repeated three times. Each repetition will be considered in this statistical treatment as a sitting. By first, second or third sittings of an experiment is meant the first, second or third time that the experiment was given.

In the tables and graphs, the unit of time is in decimals of a second.

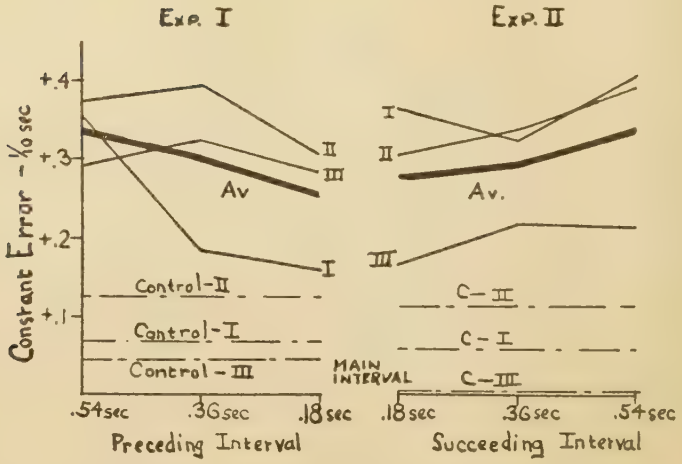


FIGURE 3.

ILLUSIONS IN EXPERIMENTS I (left) AND II (right)—Full lines represent the CE for the different intervals as indicated by the Roman numerals. Duration of the preceding or succeeding interval, abscissa; CE, in tenths of a sec., ordinates. Control CE are represented by the dot-and-dash lines.

4. Illusions in Experiments I and II. (1) In Exp. I, there is a progressive increase in the CE as the duration of the variable interval X-A, preceding the main interval A-B, is increased. The CE are combined by averaging them for the three different main intervals according to the duration of the variable preceding intervals. The average CE of the combined intervals for a preceding interval of .18 sec. is + .254 sec.; when the preceding interval is increased to .36 sec., the average CE is +.301; when the preceding interval is further increased to .54 sec., the average CE amounts to + .339 sec. See Table IV.

(2) In Exp. II, as the duration of the variable interval succeeding the main interval is increased, there is a progressive increase in the constant errors. When the duration of the variable interval is .18 sec., the average CE for the combined intervals is +.279. It is +.292 when the variable interval is increased to .36 sec., and it is further increased to +.336 sec. when the duration of the variable interval is increased to .54 sec. See Table V.

(3) (Comparison of CE in Exp. I with CE in Exp. II). The average constant errors obtained in Exps. I and II are

TABLE IV

EXPERIMENT I ILLUSIONS—Experiment I constant errors averaged for all observers and sittings for the main intervals according to the variation in the duration of the preceding interval.

Duration of Preceding Interval sec.	*Constant Errors*				
	Main Interval			*Average CE*	*Control-corrected*
	Interval I .356 sec.	*Interval II* .727 sec.	*Interval III* 1.094 sec.		
.18	+.160	+.319	+.282	+.254	+.166
.36	+.185	+.396	+.321	+.301	+.213
.54	+.351	+.376	+.291	+.339	+.251
Average CE	+.232	+.364	+.298	+.298	
Av. CE control-corrected	+.163	+.214	+.253		+.210

TABLE V

EXPERIMENT II ILLUSIONS—Experiment II constant errors averaged for all observers and sittings for the main intervals according to the variation in the duration of the succeeding interval.

Duration of Succeeding Interval sec.	*Constant Errors*				
	Main Interval			*Average CE*	*Control-corrected*
	Interval I .356 sec.	*Interval II* .727 sec.	*Interval III* 1.094 sec.		
.18	+.364	+.306	+.166	+.279	+.221
.36	+.324	+.336	+.217	+.292	+.234
.54	+.406	+.391	+.212	+.336	+.278
Average CE	+.365	+.344	+.198	+.302	
Av. CE control-corrected	+.307	+.232	+.195		+.245

on the whole symmetrical. In other words, a variable interval *preceding* a main interval causes almost as much error as a variable interval *succeeding* the main interval. As the duration of the variable interval is increased, the amount by which the error in the perception of the constant interval increases is almost the same in both experiments. (Tables IV and V and Fig. 3.)

Furthermore, there is a symmetry in the changes in the reliability in the two experiments. Table VI presents in parallel columns the changes in the reliability in the two experiments. In both experiments, the longer the main interval, the less the reliability.

5. *Practice effects.* To determine the effects of practice on the illusions in Exps. I and II, we should study the CE and VE changes in the different sittings. See Table VII. There were three sittings for each experiment. In general, there

TABLE VI

EXPERIMENTS I AND II—Reliability of differences between the reproductions of the various stimulus-patterns according to the duration of the preceding or succeeding interval.

	$\frac{D}{\sigma_{diff.}}$					
*Compared Stimulus-Patterns**	*Interval I*		*Interval II*		*Interval III*	
	Exp. I	*Exp. II*	*Exp. I*	*Exp. II*	*Exp. I*	*Exp. II*
.18 and .36	.70	.82	1.06	.59	.35	.68
.36 and .54	2.04	1.90	1.05	1.15	.39	.48
.18 and .54	2.60	2.01	1.20	1.65	.92	.38
Average	1.78	1.58	1.10	1.13	.55	.51

*A stimulus-pattern here is designated by the duration in seconds of the preceding or succeeding interval.

TABLE VII

PRACTICE EFFECTS—CE and VE for the group of observers according to the duration of the preceding or succeeding intervals by sittings.

CONSTANT ERRORS

	.18 sec.*		.36 sec.		.54 sec.		*Average CE*	
	Exp. I	*Exp. II*	*Exp. I*	*Exp. II*	*Exp. I*	*Exp. II*	*Exp. I*	*Exp. II*
First Sitting	+.384	+.492	+.448	+.520	+.537	+.524	+.456	+.512
Second Sitting	+.255	+.234	+.356	+.264	+.303	+.338	+.305	+.279
Third Sitting	+.123	+.110	+.104	+.092	+.153	+.147	+.127	+.116
Average CE	+.254	+.279	+.303	+.292	+.331	+.336	+.296	+.302

VARIABLE ERRORS

	.18 sec.*		.36 sec.		.54 sec.		*Average VE*	
	Exp. I	*Exp. II*	*Exp. I*	*Exp. II*	*Exp. I*	*Exp. II*	*Exp. I*	*Exp. II*
First Sitting	.267	.260	.323	.337	.328	.298	.306	.298
Second Sitting	.225	.230	.197	.210	.238	.233	.220	.226
Third Sitting	.199	.161	.144	.150	.149	.190	.164	.167
Average VE	.230	.219	.221	.232	.238	.240	.230	.230

*Duration of variable preceding or succeeding interval.

is a considerable increase in the accuracy (CE) and consistency (VE) in the perception of the main intervals from sitting to sitting. That the CE and the VE of the *individual observers* tend to be reduced after increased practice is evident from the data in Table VIII. All the illusions reported in the previous section tend to be cut down with increasing practice, although there is a tendency for the illusions to persist. Table VIII shows the practice effects in Exp. I as compared with the practice effects in Exp. II. From the first sitting to the second sitting in Exp. I, there is a decrease in the

TABLE VIII

PRACTICE EFFECTS—Constant errors for the different sittings and individual observers—Experiments I and II.

CONSTANT ERRORS

	First Sitting		*Second Sitting*		*Third Sitting*	
Observer	*Exp. I*	*Exp. II*	*Exp. I*	*Exp. II*	*Exp. I*	*Exp. II*
A	—.040	—.105	—.024	—.126	—.114	—.146
B	+.562	+1.000	+.559	+.677	+.297	+.059
C	+.133	—.060	—.094	—.119	—.181	—.119
D	+.241	+.041	+.033	+.022	+.044	+.192
E	+1.400	+1.680	+1.110	+.941	+.586	+.558
Average CE	+.459	+.511	+.302	+.279	+.126	+.109

Variable errors for the different sittings and individual observers—Experiments I and II.

VARIABLE ERRORS

	First Sitting		*Second Sitting*		*Third Sitting*	
Observer	*Exp. I*	*Exp. II*	*Exp. I*	*Exp. II*	*Exp. I*	*Exp. II*
A	.212	.148	.144	.179	.208	.112
B	.395	.568	.384	.344	.224	.163
C	.265	.218	.151	.191	.096	.212
D	.299	.186	.143	.125	.110	.135
E	.358	.375	.279	.290	.183	.213
Average VE	.306	.299	.220	.226	.164	.167

constant error of 33.1 per cent, and in Exp. II of 45.5 per cent. From the second to the third sitting, there is a further decrease in the constant errors in Exp. I of 58.3 per cent, and in Exp. II of 58.4 per cent. The rate of decrease in the CE in the two experiments is thus similar. As measured by the distance between the average CE level from the zero axis of inaccuracy, the illusions in Exps. I and II decrease symmetrically from sitting to sitting.

This symmetry in the effect of practice in the illusions in Exps. I and II is found to hold also for the decrease in the variable errors. In Exps. I and II, there is a decrease in the variable errors of 28.1 and 24.1 per cents from the first to the second sittings, and a decrease of 25.4 and 26.1 per cents from the second to the third sittings. In other words, the changes in the CE and VE with increasing practice show a strikingly similar reduction. Practice cuts down the magnitude of the illusions in Exps. I and II. The changes in the two experiments are symmetrical.

6. Controls. The controls determine the errors in the reproduction of an interval of time lapsing between two stimuli, and included the main intervals of Exps. I, II and III without

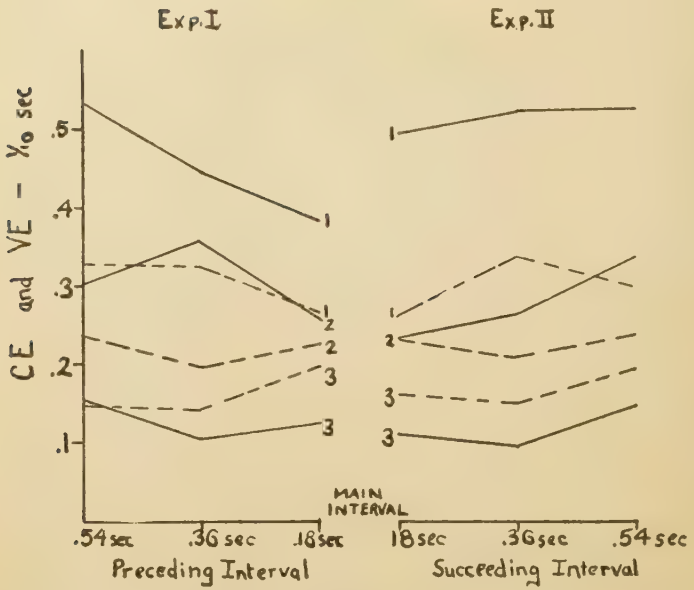


FIGURE 4.
PRACTICE EFFECTS—CE, full lines; VE, dash lines. Sittings indicated by Arabic numerals.

any extra stimulus.[10] The main intervals were repeated in the first three experiments, and also in the controls of these experiments.

In the preceding sections of this chapter, no account at all was taken of the errors in the perception of the main intervals, without any preceding or succeeding interval. Table IX presents the average reproduction and CE of the combined observers for all first six sittings for the three different intervals. However, the data cannot be regarded as a complete indication of the controls, since only 300 reactions altogether were recorded in the first three sittings.

7. CE control-corrected. To find the absolute magnitude of illusion in Exps. I and II, account must be taken of the control errors. Hence, the CE obtained in the reproduction of In-

[10] A description of the controls is given on p. 10 and p. 15. There were five different intervals in the control. In addition to the main intervals, there was one mid-way between Intervals I and II, and one mid-way between Intervals II and III.

TABLE IX

CONTROLS—Average reproductions (sec.) and constant errors for the different sittings and observers for Intervals I, II and III.

	Average Reproductions (sec.) and Constant Errors					
	Experiment I		*Experiment II*		*Experiment III*	
Main Interval	*Av*	*CE*	*Av*	*CE*	*Av*	*CE*
I	.425	+.069	.414	+.058	.470	+.114
II	.877	+.150	.839	+.112	.991	+.264
III	1.139	+.045	1.097	+.003	1.324	+.230

tervals I, II and III in the control are subtracted from the CE obtained in the reproduction of the same intervals in Exps. I, II and III. This subtraction gives what is to be called the *CE control-corrected*. Table X includes the CE control-corrected for experiments I and II. In this table, the CE are combined for the different intervals by averaging them for the different durations of the variable preceding or succeeding intervals.

TABLE X

MAGNITUDE OF ILLUSIONS AND DURATION OF THE VARIABLE INTERVALS.

	Experiment I		*Experiment II*	
Duration of Variable Interval	*CE control-corrected*	*Percentage*	*CE control-corrected*	*Percentage*
.18 sec.	+.166	92.2	+.221	122.8
.36 sec.	+.213	59.2	+.234	65.0
.54 sec.	+.251	46.5	+.278	51.5

CE control corrected for each duration of the variable interval. Progressive increase in the magnitude of the illusions in Experiment I and II with increase in the duration of the variable interval. Decrease in the percentage of this magnitude increase divided by the duration of variable.

The apparent length of the combined intervals increases 92.2 per cent more than the objective length when each of the combined intervals is preceded by a variable interval of .18 sec. (Exp. I). The apparent length of the combined intervals, when each of the main intervals is succeeded by a variable interval of .18 sec. is 122.8 per cent greater than the objective length (Exp. II).

8. Control practice effects. Observers tend to become more accurate and more consistent in their reproduction of the intervals in the controls from sitting 4 through sitting 5, but from sitting 5 through sitting 6, there is found to be little or no improvement. See Table XI.

TABLE XI

CONTROL PRACTICE EFFECTS—Constant Errors for the controls before and after the main experiment according to the sittings.

	CONSTANT ERRORS					
	Sitting 4—Exp. III		*Sitting 5—Exp. I*		*Sitting 6—Exp. II*	
Interval	*Control before*	*Control after*	*Control before*	*Control after*	*Control before*	*Control after*
I	+.103	+.121	+.069	+.033	+.053	+.053
II	+.291	+.230	+.161	+.121	+.069	+.099
III	+.167	+.083	+.063	—.276	—.024	+.037
Average CE	+.187	+.145	+.098	—.040	+.033	+.063
	VARIABLE ERRORS					
I	.099	.129	.069	.068	.091	.196
II	.192	.241	.142	.129	.117	.120
III	.202	.210	.146	.134	.148	.155
Average VE	.164	.193	.119	.110	.119	.124

TABLE XII

RELIABILITY—Reliability of differences between control and experiment intervals for Experiments III, I and II.

	$\frac{D}{\sigma_{diff.}}$					
	Exp. III—Sitting 4		*Exp. I—Sitting 5*		*Exp. II—Sitting 6*	
Main Interval	*Control before*	*Control after*	*Control before*	*Control after*	*Control before*	*Control after*
I	5.10	5.35	1.49	2.12	2.31	2.79
II	5.36	3.31	1.49	1.70	3.03	1.72
III	2.27	3.12	1.49	3.06	1.52	1.06

Table XII shows the reliability of the difference (1) between the control before the main experiment and the main experiment; (2) between the control after the main experiment and the main experiment.

CHAPTER IV

Time Illusions in Experiment III

1. Description of Exp. III. The purpose of this experiment is to study variations in the illusions in the perception of the main interval, as the duration of the preceding and succeeding intervals is changed. Exp. III is a combination of Exps. I and II. In Exp. III, a constant interval of time is both preceded and succeeded by variable time intervals. A stimulus-pattern *X-A-B-Z* in the experiment consists of four light flashes: X, A, B, and Z (Diagram C, Fig. 1). The subject was instructed to reproduce the interval between the second and third lights directly after the fourth.

2. Time machine settings. The same machine settings used in Exps. I and II were put into play in Exp. III, and all the main and variable intervals were the same. Following the nomenclature of Woodrow, the stimulus-patterns in this experiment may be designated by a combination of letters representing the relative duration of the preceding and succeeding intervals. *S* represents a short interval (.18 sec.); *M* represents a medium interval (.36 sec.); and *L*, a long interval (.54 sec.). For example, *S-S* represents a stimulus-pattern with a main interval of time both preceded and succeeded by a short interval (.18 sec.).

3. Illusions in Exp. III. In Exps. I and II, symmetrical

TABLE XIII

Experiment III Illusions—Constant errors in seconds averaged for all sittings and observers for the different intervals according to the duration of the variable preceding and succeeding intervals.

	CONSTANT ERRORS				
Stimulus-Pattern	*Interval* I .356 sec.	*Interval* II .727 sec.	*Interval* III 1.094 sec.	*Average CE*	*Average CE control-corrected*
S-S*	+.331	+.332	+.290	+.318	+.115
L-S	+.471	+.421	+.197	+.363	+.160
M-M	+.444	+.589	+.314	+.449	+.246
S-L	+.560	+.501	+.317	+.459	+.256
Average CE	+.452	+.461	+.279		
Average CE control-corrected	+.338	+.197	+.049		

*S-S is stimulus-pattern consisting of a main interval (I, II or III), a short preceding interval (.18 sec.) and a short succeeding interval (.18 sec.).

variations in the illusions were found. There was a progressive increase in the magnitude of the illusions in the perception of the main interval as the duration of the *preceding* variable interval (Exp. I), or the *succeeding* variable interval (Exp. II) increased. Similarly, in Exp. III, there is a proportional increase in the magnitude of the illusions as the duration of the preceding and succeeding intervals is varied. Depending on the particular combination of the variable preceding and succeeding intervals, there are certain differences in the illusions.[11]

In Table XIII, the CE is shown for the different stimulus-patterns, for the three intervals, and for their averages. The stimulus-patterns arranged according to decreasing amounts of the average CE are: *S-L, M-M, L-S,* and *S-S.* This order of the illusions is however not the same in the different intervals. In Interval III, the *M-M* and *S-L* illusions are equal and only slightly greater than the *S-S* illusion.

TABLE XIV

EXPERIMENT III—Reliability of differences between the various stimulus-patterns according to the main intervals.

Compared Stimulus-Patterns	$\frac{D}{\sigma_{diff.}}$ *Interval I*	*Interval II*	*Interval III*
L-S and S-L	1.61	.92	1.40
S-L and M-M	1.04	1.53	——
M-M and S-S	1.41	2.98	.68
L-S and M-M	1.29	2.49	1.11
L-S and S-S	1.63	1.14	1.39
S-L and S-S	2.90	2.91	.69

A fair degree of reliability of the differences between the illusion obtained for the variable stimulus-patterns in Interval

[11] An interesting comparison of Exps. I, II and III can be made by counting time units of the variable preceding and succeeding intervals. *S, m,* and *l* would count as one, two and three units, and when combined in the stimulus-patterns of Exp. III as *l-s, s-l, m-m* these intervals count as four units. If the control corrected CE are plotted for these experiments, with the time units as the abscissa and the CE in tenths of a sec. as the ordinates, it can be seen that there is a proportional increase in the constant error in the three experiments as time units of the preceding and succeeding intervals increase. But the CE control corrected curves of Exp. I and II are symmetrical to and larger than the curve of Exp. III CE control corrected. The curve of the Exp. I CE control corrected is symmetrical to that of Exp. II, and is somewhat smaller than it. This question of the constant relation between increasing magnitude of the illusion and the time of the preceding or succeeding intervals was suggested, from the data, by Professor Woodworth.

I and II is indicated by the data in Table XIV. In Interval I, the reliability of the differences between *M-M* and *S-S*, *S-L* and *S.S* is quite high: in Interval I, $\frac{D}{\sigma_{diff.}}$ is 1.41 and 2.9, and in Interval II, 2.90 and 2.91. As in Exps. I and II, the longer the main interval, the less the reliability.

4. Practice effects. The order of illusions in Exp. III changes slightly with increased practice. This is shown (Tables XV and XVI) by arranging the illusions in the order

TABLE XV

PRACTICE EFFECTS—CE and VE for the group of observers by sittings, intervals and stimulus-patterns (Experiment III).

		CONSTANT ERRORS			VARIABLE ERRORS		
Interval	*Stimulus-Pattern*	*Sitting 3a*	*Sitting 3b*	*Sitting 4*	*Sitting 3a*	*Sitting 3b*	*Sitting 4*
	S-S	+.370	+.371	+.252	.177	.213	.141
I	L-S	+.511	+.525	+.377	.330	.315	.169
.356 sec.	M-M	+.565	+.485	+.284	.228	.283	.122
	S-L	+.666	+.545	+.469	.397	.248	.144
	S-S	+.482	+.317	+.196	.282	.230	.214
II	L-S	+.490	+.518	+.255	.303	.267	.189
.727 sec.	M-M	+.741	+.633	+.392	.239	.248	.165
	S-L	+.620	+.579	+.303	.307	.230	.182
	S-S	+.474	+.325	+.060	.306	.321	.224
III	L-S	+.309	+.243	+.040	.346	.185	.173
1.094 sec.	M-M	+.488	+.306	+.147	.260	.256	.178
	S-L	+.442	+.366	+.144	.370	.264	.210
General Average		+.513	+.435	+.242	.295	.255	.176

TABLE XVI

PRACTICE EFFECTS—CE and VE for the combined intervals by stimulus-patterns and sittings (Experiment III).

	CONSTANT ERRORS			VARIABLE ERRORS		
Stimulus-Pattern	*Sitting 3a*	*Sitting 3b*	*Sitting 4*	*Sitting 3a*	*Sitting 3b*	*Sitting 4*
S-S	+.442	+.341	+.169	.255	.255	.193
L-S	+.437	+.429	+.224	.326	.256	.177
M-M	+.598	+.474	+.274	.242	.262	.155
S-L	+.576	+.497	+.305	.358	.248	.179
Average	+.513	+.435	+.243	.295	.255	.176

of magnitude for the different stimulus-patterns according to sittings. In the last two sittings, the order of illusions in decreasing magnitude is *S-L*, *M-M*, *L-S* and *S-S*, and is somewhat comparable to that obtained by Woodrow in his experi-

ment.[12] As in the previous experiments, with increased practice the average CE and VE levels are reduced. Table XVII presents the CE and VE averaged for the different observers and sittings. The average CE for the combined observers declines from sitting 3a to 3b (the first half of the third sitting to the second half), from + .513 to + .435; and from sitting 3b to sitting 4 from + .435 to + .243. The average VE declines from .295 to .255 from sitting 3a to 3b; and from .255 to .176 from 3b to sitting 4.

TABLE XVII

PRACTICE EFFECTS—Constant errors and variable errors for the combined Experiment III stimulus-patterns for each observer and sitting.

	CONSTANT ERRORS *Sittings*			VARIABLE ERRORS *Sittings*		
	3a	*3b*	*4*	*3a*	*3b*	*4*
A	+.021	—.068	+.010	.191	.167	.149
B	+.980	+.573	+.175	.515	.411	.222
C	—.161	—.264	—.149	.142	.134	.128
D	+.078	+.173	+.075	.182	.166	.125
E	+1.643	+1.77	+1.110	.447	.398	.256
General Average	+.512	+.437	+.244	.296	.255	.176

5. Controls. As mentioned in the preceding chapter, data for the controls in this experiment are set forth in Tables IX, XI and XII.

[12] His order was *L-S, M-M, S-L and S-S.* (See Chapter I, p. 8.)

CHAPTER V

Illusions in Experiments I and II Compared with the Illusions in Experiment III

1. Sum of Exps. I and II CE compared with Exp. III CE. In this chapter, data of Exp. III will be compared with the data of Exps. I and II, set forth in the preceding chapters. These three experiments have the main interval A-B in common. In addition to this common element A-B, in *X-A-B*, the Exp. I stimulus-pattern, there is a variable preceding interval, and in *A-B-Z*, the Exp. II stimulus-pattern, there is a variable succeeding interval. But in Exp. III there are both variable preceding and succeeding intervals. For equivalent variable preceding and succeeding intervals, the CE in Exps. I and II are added together and this sum is compared with the CE in Exp. III. This comparison is related to perception of form and pattern, but is not presented as a critical test of the Gestalt theory.

The sum of the CE in Exps. I and II exceeds the CE in Exp. III, for equivalent variable intervals, in all the cases in Table XVIII. For the stimulus-pattern *L-S*, the sum of the CE in Exps. I and II exceeds the CE in Exp. III by .244 or 51.8 per cent. In *L-S*, there is a *long preceding* interval of .54 sec., and a *short succeeding* interval of .18 sec. (Exp. III).

Table XVIII

This table shows how the sum of the CE of Experiments I and II exceeds the CE of Experiment III for equivalent and variable intervals.

Experiment III Duration of Variable Intervals (sec.)	Stimulus-Pattern	*Interval I* CE*>	%CE†>	*Interval II* CE>	%CE>	*Interval III* CE>	%CE>	*Average* CE>
.18—.18	S-S	+.193	58.3	+.293	88.3	+.158	54.5	+.215
.54—.18	L-S	+.244	51.8	+.261	62.0	+.260	134.0	+.255
.36—.36	M-M	+.065	14.6	+.143	24.3	+.224	71.3	+.144
.18—.54	S-L	+.006	11.1	+.209	41.7	+.177	55.8	+.131
General Average		+.127	33.9	+.227	54.1	+.205	78.9	

*$CE> = (CE_{\text{Exp. I}} + CE_{\text{Exp. II}}) - CE_{\text{Exp. III}}$

†$\%\ CE = \dfrac{CE>}{CE_{\text{Exp. III}}}$

These variable intervals are equivalent in themselves to the sum of a *long preceding* interval of .54 sec. in Exp. I, and a *short succeeding* interval of .18 sec. in Exp. II, but in their illusion-producing effect they are 51.8 per cent greater.

2. Effects of practice. This relation between the sum of the CE in Exps. I and II and the CE in Exp. III varies with practice. In the first two sittings of these experiments, the sum of the CE in Exps. I and II is greater than the CE in Exp. III, but in the third sitting the CE in Exp. III exceeds the sum of the CE in Exps. I and II. An average of the amount of excess for the different stimulus-patterns according to the different sittings shows that this excess is reduced from the first to the second sitting from 88.3 per cent to 27.9 per cent, and in the last sitting it is negligible.

TABLE XIX

PRACTICE EFFECTS—This table shows how the relation between the excess of the sum of Experiments I and II CE over Experiment III CE is cut down with increased practice. For definition of column headings, see Table XVIII.

Experiment III Duration of Variable Intervals (sec.)	Stimulus-Pattern	*First Sitting* CE>	%CE>	*Second Sitting* CE>	%CE>	*Third Sitting* CE>	%CE>	*Average* CE>
.18—.18	S-S	+.434	98.2	+.148	36.3	+.064	37.9	+.215
.54—.18	L-S	+.592	135.5	+.108	25.2	+.039	17.4	+.246
.36—.36	M-M	+.370	61.9	+.146	30.8	—.078	—28.5	+.144
.18—.54	S-L	+.332	57.6	+.096	19.3	—.035	—11.5	+.131
General Average		+.432	88.3	+.125	27.9	—.003	+ 5.1	

3. Control corrected CE of Exps. I, II and III. This comparison of the sum of the CE in Exps. I and II with the CE in Exp. III may also be made with the CE control corrected.[13] In this comparison, the CE of the third sittings only of the various experiments will be considered; since, as explained above, a full control was given in those sittings only. In the third sitting, the sum of the CE control corrected of Exps. I and II exceeds slightly the CE of Exp. III. This is shown in Table XX.

4. Conclusions. The sum of the CE in Exps. I and II exceeds the CE in Exp. III for equivalent variable preceding and suc-

[13] An explanation of the CE control corrected is given in chapter III, p. 24.

TABLE XX

COMPARISON OF EXPS. I AND II CE WITH EXP. III CE FOR THE THIRD SITTING ONLY—THE CE CORRECTED FOR CONTROLS.

Stimulus-Pattern	*CE>*
S-S	+.165
L-S	+.140
M-M	+.023
S-L	+.066

ceeding intervals. Practice cuts down the excess, and in the third sitting this excess approaches zero. The conclusion reached from this is that, in certain instances, the whole is less than the sum of its parts and the relation between the whole and the sum of its parts is a variable one due to the influence of practice.

CHAPTER VI

Time Illusions in Experiment IV

1. An interval divided into parts. An analysis is made in this chapter of the errors in the perception of the main interval when divided into two variable intervals. It will be shown from experimental data that the apparent length of a constant interval depends upon the relative duration of its parts. In this experiment, the stimulus-pattern A-Y-B consists of three light flashes, A, Y and B (Diagram D, Fig. 1). The time between A and B is always constant, but the time between A and Y, and between Y and B, is variable.

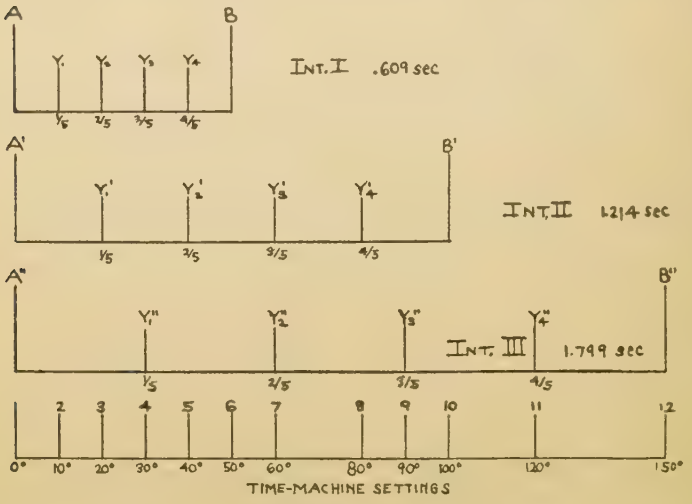


Figure 5.

Machine Time Chart II.—Upper three diagrams represent the three different main intervals each split into fifths. The lower diagram, drawn to scale, indicates how twelve mercury contacts were arranged on the circumference of the time machine for Exp. IV.

2. Time machine settings. There are three main intervals in the experiment: Interval I between flashes A-B (.609 sec.) Interval II between flashes A′ and B′ (1.214 sec.) and Interval III between flashes A″ and B″ (1.799 sec.). Each of three main intervals is split into fifths, so that in the different

stimulus-patterns an extra stimulus may be shifted along the fifths. The time machine settings are so arranged that an extra flash Y, Y′, or Y″ may come 1/5, 2/5, 3/5, or 4/5 of the time between flashes A and B of Interval I, between flashes A′ and B′ of Interval II, between flashes A″ and B″ of Interval III. *(Machine time, Chart II, Fig. 5.)* This arrangement of the time machine settings allows the experimenter to put into play twelve different stimulus-patterns consisting of any one of three main intervals, with the time of the extra stimulus varied along the fifths.

3. Illusions in Exp. IV. The apparent length of the main interval (A-B) divided into two variable intervals by an intervening stimulus Y, is found to be much greater than the objective length of the main interval. This difference between the apparent length and the objective length of the main interval (A-B) decreases as the time between stimuli A and Y increases. Sees Tables XXI and XXII and Fig. 6.

TABLE XXI

EXPERIMENT IV—CE and VE averaged for the group of observers and all sittings according to the position along the fifths into which the main intervals are split by an extra stimulus

CONSTANT ERRORS

Position of the Intervening Stimulus	*Interval I .609 sec.*	*Interval II 1.214 sec.*	*Interval III 1.799 sec.*	*Average CE*	*Av CE control-correct*
1/5	+.526	+.305	+.137	+.323	+.261
2/5	+.412	+.383	+.118	+.304	+.242
3/5	+.386	+.244	+.026	+.219	+.157
4/5	+.371	+.110	—.185	+.099	+.037
Average CE	+.424	+.261	+.024		
% Av. CE	69.7	21.5	1.3		
D*	1.55	1.95	2.43		
$\frac{}{\sigma_D}$					
Control CE†	+.165	+.109	—.088		

VARIABLE ERRORS

Position of the Intervening Stimulus	*Interval I*	*Interval II*	*Interval III*	*Average VE*
1/5	.227	.215	.296	.246
2/5	.270	.239	.332	.280
3/5	.207	.208	.268	.228
4/5	.208	.224	.319	.250
Average VE	.228	.221	.304	.251

*From Table XXIII
†From Table XXVI

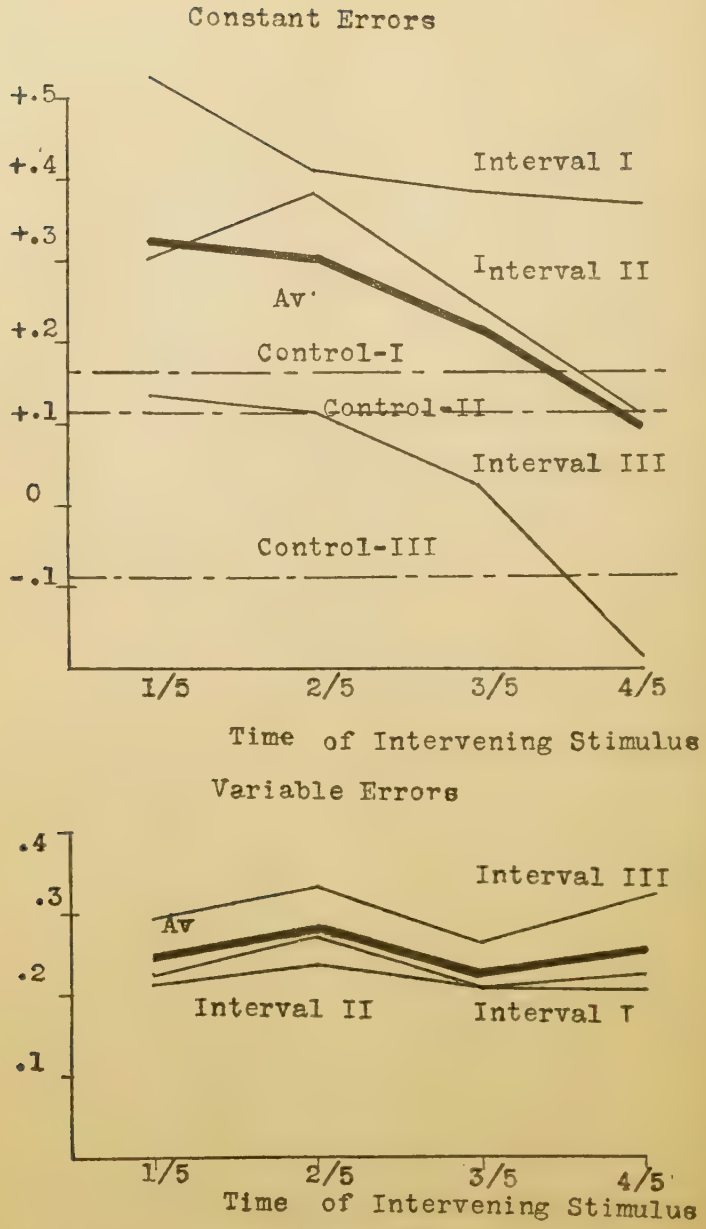


FIGURE 6.

ILLUSIONS IN EXPERIMENT IV—(Table XXI) CE, upper graph, VE, lower graph, with data for individual observers and sittings combined according to the main intervals. Time of intervening stimulus, abscissa; errors in tenths of a second, ordinates.

TABLE XXII

EXPERIMENT IV—Constant errors and variable errors for individual observers averaged for all the sittings according to intermediate-stimulus position.

Interval	Intermediate Stimulus	CONSTANT ERRORS Observers A	B	C	D	E	VARIABLE ERRORS Observers A	B	C	D	E
I .609 sec.	1/5	+.257	+.648	+.250	+.459	+1.017	.244	.415	.117	.161	.198
	2/5	+.103	+.491	+.229	+.218	+1.017	.229	.537	.131	.216	.236
	3/5	+.121	+.265	+.195	+.269	+1.078	.129	.374	.149	.162	.221
	4/5	+.090	+.391	+.167	+.255	+ .951	.127	.368	.133	.177	.235
II 1.214 sec.	1/5	—.100	+.497	—.131	+.071	+1.188	.152	.341	.144	.187	.251
	2/5	+.055	+.607	—.040	+.080	+1.215	.161	.487	.146	.153	.250
	3/5	—.154	+.398	—.083	+.021	+1.037	.193	.327	.145	.162	.214
	4/5	—.234	+.145	—.182	+.004	+ .816	.271	.288	.164	.198	.163
III 1.799 sec.	1/5	—.522	+.481	—.519	—.121	+1.365	.369	.422	.181	.191	.316
	2/5	—.394	+.602	—.428	—.181	+ .993	.311	.535	.238	.205	.373
	3/5	—.341	+.112	—.408	—.201	+ .968	.327	.438	.157	.223	.194
	4/5	—.625	—.196	—.611	—.276	+ .781	.296	.459	.207	.273	.360
General Average		—.145	+.370	—.130	+.050	+1.036	.234	.416	.159	.192	.251

TABLE XXIII

EXPERIMENT IV—Reliability of differences between the various stimulus-patterns differentiated according to intermediate-stimulus position.

Compared Stimulus-Patterns	Interval I D	$\frac{D}{\sigma_D}$	Interval II D	$\frac{D}{\sigma_D}$	Interval III D	$\frac{D}{\sigma_D}$	Av. $\frac{D}{60}$
1/5 and 2/5	+.113	1.508	—.078	1.280	+.019	1.709	1.499
2/5 and 3/5	+.026	.892	+.139	2.180	+.092	1.887	1.653
3/5 and 4/5	+.014	.998	+.134	1.880	+.211	2.450	1.776
1/5 and 3/5	+.149	2.087	+.061	1.240	+.111	2.644	1.990
1/5 and 4/5	+.154	2.360	+.195	2.536	+.322	3.130	2.675
2/5 and 4/5	+.041	1.448	+.274	2.574	+.204	2.768	2.263
Average $\frac{D}{\sigma_D}$		1.55		1.95		2.43	

INDIVIDUAL OBSERVERS—Reliability of critical differences—$\frac{D}{\sigma_D}$

Compared Stimulus-Patterns	Interval	Observer A	B	C	D	E
1/5 and 4/5	I	2.86	2.36	2.28	3.23	1.08
	II	2.08	3.12	.74	1.26	5.48
	III	1.08	4.39	1.64	2.46	6.08
2/5 and 4/5	I	2.35	1.69	1.63	.57	1.00
	II	4.44	3.15	2.73	1.60	5.95
	III	2.80	4.51	3.42	1.06	2.05
3/5 and 4/5	I	.77	1.29	.66	.25	2.02
	II	1.16	2.59	1.82	.35	3.48
	III	3.08	2.16	3.70	1.09	2.22

The reliability of the differences between the errors obtained in the perception of the various stimulus-patterns is fairly high. The average $\frac{D}{\sigma_{diff.}}$ for the various stimulus-patterns compared in Interval I is 1.55, in Interval II 1.95, and in Interval III 2.43. The data on reliability are presented in Table XXIII.

4. Practice effects. Practice diminishes the VE, and especially the CE, sometimes changing the original positive CE to a negative one, as can be seen in Tables XXIV and XXV, and in Figs. 7, 8 and 9. But, in spite of this general reduction

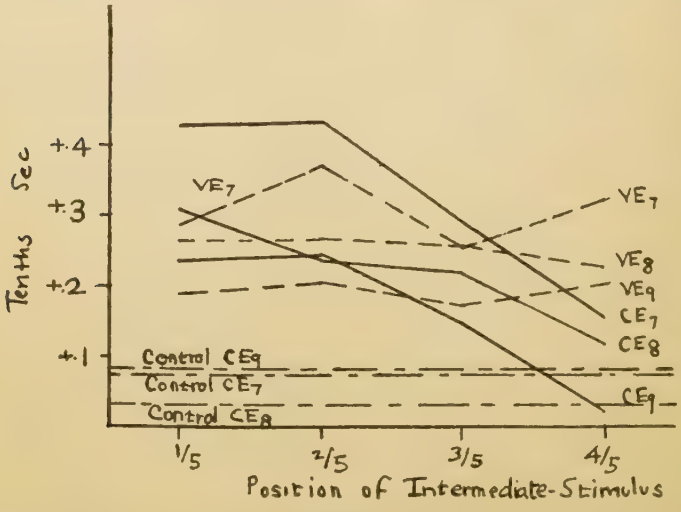


FIGURE 7.
PRACTICE EFFECTS (Table XXV)—CE (full lines) and VE (dash lines) plotted by sittings (Arabic numerals) for the combined intervals—Control CE (dot-and-dash lines) included.

of the CE, the relation mentioned above continues to hold, namely, that the over-estimation is greatest when the extra stimulus comes early in the judged interval and least when the extra stimulus comes late. That is, the effect of the position of the extra stimulus remains the same in all stages of practice.

5. Controls. The average CE of each of the main intervals in Exp. IV exceeds the CE of the same interval in the controls.

TABLE XXIV

PRACTICE EFFECTS in EXPERIMENT IV—Constant errors and variable errors for the different intervals and stimulus-patterns averaged for all observers by sittings.

Interval	*Stimulus-Pattern*	CONSTANT ERRORS *Sitting 7*	*Sitting 8*	*Sitting 9*	VARIABLE ERRORS *Sitting 7*	*Sitting 8*	*Sitting 9*
I .609 sec.	1/5	+.587	+.570	+.422	.210	.292	.179
	2/5	+.466	+.407	+.362	.349	.274	.186
	3/5	+.426	+.415	+.315	.213	.240	.168
	4/5	+.432	+.385	+.296	.221	.226	.178
Average		+.478	+.444	+.349			
Average Control		*+.176*	*+.165*	*+.155*			
II 1.214 sec.	1/5	+.413	+.286	+.217	.255	.219	.172
	2/5	+.500	+.329	+.321	.324	.206	.188
	3/5	+.318	+.225	+.184	.233	.222	.170
	4/5	+.165	+.154	+.010	.316	.170	.185
Average		+.349	+.249	+.183			
Average Control		*+.103*	*+.080*	*+.145*			
III 1.799 sec.	1/5	+.288	+.063	+.065	.399	.277	.212
	2/5	+.328	—.027	+.054	.436	.317	.243
	3/5	+.124	+.019	—.065	.310	.314	.179
	4/5	—.125	—.185	—.245	.426	.272	.259
Average		+.154	—.130	—.048			
Average Control		*—.061*	*—.150*	*—.054*			

	General Average CE				General Average VE		
Exp. IV	+.327	+.220	+.161	Exp. IV	.308	.253	.193
Control	*+.073*	*+.032*	*+.082*	*Control*	*.255*	*.213*	*.214*

As set forth in Table XXVI, the control CE for the three main intervals averages + .165, + .109 and — .088, while the CE for the same intervals affected by an extra internal stimulus in Exp. IV averages + .424, + .261 and + .024 respectively.

The controls included all the main intervals of Exp. IV, that is, Intervals I, II and III, and two other intervals, one between machine units one and four (.364 sec.) and the other between machine units one and eleven (1.422 sec.). The only difference between the main intervals and the controls in Exp. IV is that in the controls the main intervals are undivided, and in Exp. IV they are divided. There were altogether 1,800 reproductions of the intervals (main intervals I, II and III) in the controls, and the same number of reproductions of those main intervals in Exp. IV.

The reliability of the differences between the reproductions of the main intervals in Exp. IV and in the controls is high. The average $\frac{D}{\sigma_{diff.}}$ is 8.1 for Interval I, 4.77 for Interval II, and 4.03 for Interval III.

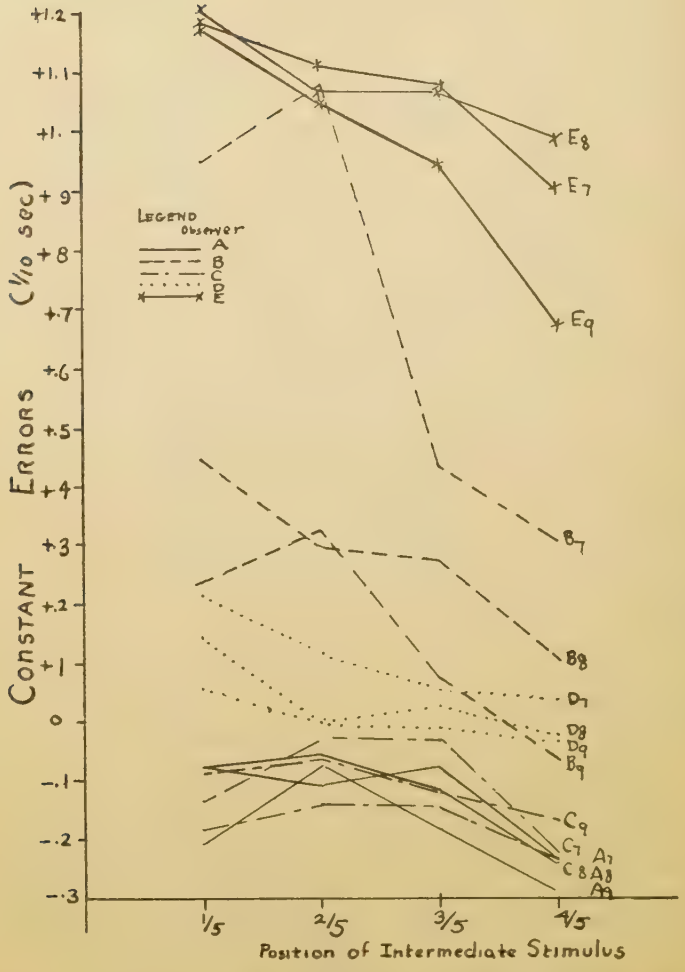


FIGURE 8.

INDIVIDUAL OBSERVERS—CE for individual observers, all intervals combined according to the position of the intermediate stimulus by sittings. (Letters represent the observers; numerals, the sitting. E. g., E_8 is the CE curve for observer E in sitting 8.)

TABLE XXV

PRACTICE EFFECTS in EXPERIMENT IV.—Constant errors for individual observers by sittings for the different stimulus-patterns with the intervals combined. (Average variable errors in italics.)

	Sitting 7 *Position of Intermediate Stimulus*				*Average*	
Observer	*1/5*	*2/5*	*3/5*	*4/5*	*CE*	*VE*
A	— .079	— .110	— .079	—.233	— .125	*.282*
B	+ .948	+1.079	+ .430	+.303	+ .690	*.563*
C	— .135	— .030	— .033	—.223	— .105	*.169*
D	+ .215	+ .115	+ .051	+.038	+ .105	*.251*
E	+1.188	+1.103	+1.079	+.900	+1.067	*.273*
Average CE	+ .426	+ .431	+ .289	+.157	+ .326	
Average VE	*.288*	*.370*	*.252*	*.321*		*.308*

	Sitting 8				*Average*	
Observer	*1/5*	*2/5*	*3/5*	*4/5*	*CE*	*VE*
A	— .079	— .054	— .113	—.241	— .122	*.283*
B	+ .440	+ .299	+ .272	+.101	+ .278	*.399*
C	— .181	— .140	— .147	—.231	— .175	*.143*
D	+ .142	+ .005	+ .028	—.022	+ .038	*.163*
E	+1.209	+1.071	+1.060	+.985	+1.081	*.274*
Average CE	+ .306	+ .236	+ .220	+.118	+ .220	
Average VE	*.263*	*.266*	*.259*	*.223*		*.253*

	Sitting 9				*Average*	
Observer	*1/5*	*2/5*	*3/5*	*4/5*	*CE*	*VE*
A	— .207	— .073	—.182	—.294	—.189	*.136*
B	+ .238	+ .322	+.072	—.064	+.142	*.286*
C	— .084	— .069	—.122	—.171	—.111	*.166*
D	+ .053	— .003	+.011	—.033	+.007	*.164*
E	+1.172	+1.051	+.944	+.664	+.957	*.214*
Average CE	+ .235	+ .246	+.145	+.020	+.162	
Average VE	*.188*	*.206*	*.172*	*.207*		*.194*

6. Practice effects in the controls. Although there is considerable learning of the main intervals in Exp. IV, there is little or no improvement in the accuracy of reproduction of the same intervals included in the controls.[14] The average CE level of the control intervals in sitting nine is slightly higher even than that in sitting seven. See Table XXVII. Consequently, the average CE level of the Exp. IV intervals

[14] One of the extra control intervals (.364 sec.) was one of the main intervals in the first six sittings (in Exps. I, II and III). There was no further improvement in the reproduction of the interval.
Its CE in sittings 4, 5 and 6 were + .114, + .069, and +.059.
In sittings 7, 8 and 9, the CE are + .067, + .054, and + .069.

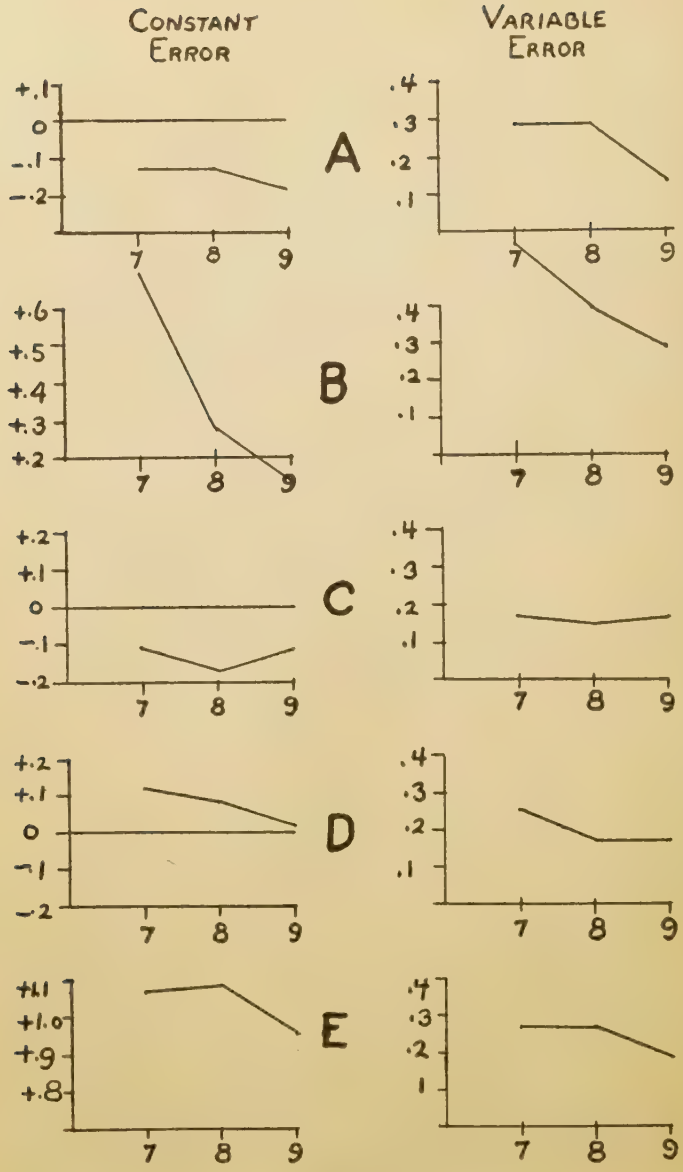


FIGURE 9.

INDIVIDUAL CURVES—Average CE (left) and average VE (right) of the individual observers for all the Exp. IV stimulus-patterns combined according to sittings (abscissa, Arabic numerals).

TABLE XXVI

CONTROL—Constant errors averaged for all observers by sittings and intervals.

Control Main Interval	CONSTANT ERRORS Setting 7	Sitting 8	Sitting 9	Average CE
I .609 sec.	+.176	+.165	+.155	+.165
II 1.214 sec.	+.103	+.080	+.145	+.109
III 1.799 sec.	—.061	—.150	—.054	—.088

TABLE XXVII

CONTROL PRACTICE EFFECTS—Constant errors and variable errors for individual observers averaged by sittings.

Observer	CONSTANT ERRORS Sitting 7	Sitting 8	Sitting 9	Av. CE	VARIABLE ERRORS Sitting 7	Sitting 8	Sitting 9	Av. VE
A	—.379	—.320	—.335	—.311	.206	.144	.172	.174
B	+.398	+.190	+.218	+.269	.501	.375	.348	.408
C	—.217	—.291	—.132	—.213	.177	.185	.199	.187
D	+.046	+.049	+.045	+.047	.165	.189	.136	.163
E	+.514	+.527	+.617	+.553	.225	.171	.213	.203
General Average	+.072	+.031	+.082		.255	.213	.214	

tends to meet the average CE level of the control intervals.[15]

The illusions in this experiment tend to persist despite the increasing accuracy and consistency in the reproduction of the Exp. IV main intervals. This persistence cannot be due to a mere lack of interest on the part of the subjects as suggested by Woodrow.[16] The fact that there is learning of the divided main intervals in Exp. IV and no learning of the same intervals when undivided in the controls cannot easily be explained by any lack of interest.

7. Relation between the change in the parts and the whole. This experiment centers on the relation between the change in the parts and the whole. The main interval A-B may be considered as the *whole*, and as such is one of the control intervals. An extra stimulus Y coming within A-B divides it in two, the *parts*. There is a slight error in the perception of the undivided interval A-B in the controls. The apparent length of the main interval A-B increases when an intervening stimulus Y divides this interval in two. When A-Y is short, the difference between the objective and apparent length of A-B is

[15] The differences between control and Exp. IV CE in sittings 7, 8 and 9 are +.302, +.279, and +.194 (Interval I); +.246, +.169, +.038 (Interval II); +.215, +.020, +.006 (Interval III).

[16] See above, page 8.

greatest, and the difference is least when A-Y is long. The magnitude of the illusion varies with the duration of the parts. In conclusion, a change in the relations between parts of an interval affects the accuracy of perception of the entire interval.

8. Illusions incidental to the configuration. The illusions obtained in Exp. IV are due to the influence of the parts on the perception of the complete pattern, and, on the other hand, the illusions in Woodrow's experiments are due, as explained by that investigator, to the influence of the complete pattern on the perception of the parts.[17] All these time illusions involve either the influence of the parts of a stimulus-pattern on the perception of the whole, or the influence of the whole stimulus-pattern on the perception of the parts. The interdependence of the parts and the whole relates these illusions to other kinds of illusions, as in the case of divided space. In space perception there are illusions similar to the illusions occurring in the comparison of short time intervals. This was suggested by Woodworth, who would class such illusions as "incidental to the configuration,"[18] and more recently, as "due to imperfect isolation of the fact to be perceived."[19] The influence of the whole on the parts, shown experimentally in the perception of time patterns by Woodrow and in the present investigation (Exp. III), may be said to be due to imperfect isolation of the fact to be perceived, due to the whole configuration.

[17] See above, page 9.

[18] Ladd and Woodworth, Elements of Physiological Psychology, 1911, 440.

[19] Psychology, rev. ed., 1929, 416. This explanation of Exps. III and IV illusions as "incidental to the configuration" is not applied here to Exps. I and II.

CHAPTER VII

Summary and Conclusions

The present investigation makes a fairly systematic experimental exploration of a simple situation consisting of three or four successive flashes of a light. This series of flashes constitutes a pattern which includes a main interval between two flashes, and a preceding or succeeding interval. The situation is simplified because the stimuli are of one sense modality, *lights only*.

Outline of the Experiments

Experiment I. A stimulus-pattern *X-A-B* consists of three light flashes. There are nine different stimulus-patterns. The subject reproduces the interval (A-B) between the second and third flashes directly after the third. For the control, the instructions are to reproduce the interval between first and second flashes directly after the second. One thousand, three hundred forty-eight Exp. I, and 1,100 control reactions were recorded.

Experiment II. A stimulus-pattern *A-B-Z* consists of three light flashes. The interval (A-B) between the first and second flashes is reproduced directly after the third. Nine different stimulus-patterns are put into play. One thousand, three hundred forty-eight Exp. II, and 1,100 control reactions.

Experiment III. A stimulus-pattern *X-A-B-Z* consists of four light flashes. The interval A-B between the second and third flashes is reproduced directly after the fourth. Twelve stimulus-patterns. One thousand, seven hundred eighty Exp. III, and 1,100 control reactions.

Experiment IV. A stimulus-pattern *A-Y-B* consists of three light flashes. The interval A-B between the first and third is reproduced directly after the third. Twelve different stimulus-patterns. One thousand, eight hundred Exp. IV, and 3,000 control reactions.

A. Excess of the Apparent Length over the Objective Length of the Main Interval

1. (Exp. I). When an extra stimulus X comes before the main interval A-B, there is a progressive increase in the apparent length of the main interval A-B, as X-A (preceding interval) is increased.

Duration of the Preceding Interval X-A	*Difference Between Apparent and Objective Length of A-B*
.18 sec.	+ .166 sec.
.36 sec.	+ .213 sec.
.54 sec.	+ .251 sec.

2. (Exp. II) When an extra stimulus Z comes after the main interval A-B, there is also a progressive increase in the apparent length of A-B as B-Z (succeeding interval) is increased.[20]

Duration of the Succeeding Interval B-Z	*Difference Between Apparent and Objective Length of A-B*
.18 sec.	+ .221 sec.
.36 sec.	+ .234 sec.
.54 sec.	+ .278 sec.

3. (Exp. III) When the main interval A-B is both preceded by an extra stimulus X and followed by an extra stimulus Y, its apparent length is increased somewhat in proportion to the combined duration of X-A and B-Y, but with some peculiarities such as that (a) a combination of the preceding and following extra stimuli gives an illusion that is typically smaller than the sum of the illusions produced by the extra stimuli applied separately in Exps. I and II; (b) the illusion depends not only on the sum of the durations of the preceding and following intervals, but upon their relative size. Thus, if *S*, *M*, and *L* denote respectively a short, medium and long interval added either before or after the main interval, then, though S + L, L + S, and M + M are all equal in duration, S + L gives the greatest illusion, followed in order by M + M and L + S, with S + S consistently giving the smallest illusion.

4. (Exp. IV). When an extra stimulus Y comes within the main interval A-B, the difference between the apparent and objective length of A-B is greatest when A-Y is shortest, and tends to reach zero as the length of the interval A-Y is increased.

5. The magnitude of the illusions varies inversely with the duration of the main intervals in all the experiments.[21]

B. The Effects of Practice on the Illusions

1. The illusions tend to persist with increased practice, especially in Exp. IV.

2. The average CE and VE levels are lowered from sitting to sitting.

[20] The data here are based on the CE control corrected.
[21] In Exp. I, this holds for the percentage CE.

3. Individual observers become more accurate and consistent in their reproduction of the intervals in Exps. I, II, III and IV with increased practice.

4. The excess of the sum of the CE in Exps. I and II over the Exp. III CE is cut down to a large extent.

C. The Controls

The controls measure the CE and VE in the estimation of a plain time interval (without any extra stimulus) between two stimuli. Short time intervals are slightly overestimated. The controls show the effects of practice on the accuracy of estimation of time intervals. At first, the accuracy improves, but a limit is soon reached. Improvement in judging the same intervals having an extra stimulus before, within or after them is much more rapid, and continues longer.

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